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The Effect of Varying Concentrations of Vitamin C on Performance, Blood Metabolites, and Carcass Characteristics of Steers Consuming a Common High Sulfur Diet

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Summary and Implications

The data support the conclusion that supplementing a rumen-protected vitamin C (**VC**) source to yearling feedlot steers consuming a high sulfur (**S;** 0.55%) diet tends to increase feed efficiency and ribeye area (**REA**), while minimal effects were noted on blood metabolites or marbling score.

Introduction

Due to the rise in corn prices, producers have been encouraged to seek alternative feedstuffs for feedlot cattle, such as dried distillers grains with solubles (**DDGS**). While DDGS provide an ample source of energy and protein, these products often contain increased concentrations of S, potentially limiting the inclusion rate in cattle diets. High S diets hinder live animal performance and carcass characteristics, specifically decreasing DMI, average daily gain (**ADG**), hot carcass weight (**HCW**), and marbling score.

The role of VC as an antioxidant is well defined. However, the daily VC requirement by finishing cattle is currently unknown, as cattle can synthesize VC from glucose in the liver. Researchers have observed the quantity of circulating VC decreases in fattening cattle and across the first 90 d of cattle being fed a 0.55% S diet. Vitamin C supplementation may enhance marbling scores of cattle receiving a 0.55% S diet, increase REA, and prevent the decline of circulating VC in finishing steers. It is still unclear what concentration of supplemental VC is needed to support live and carcass-based performance in cattle fed high S diets. Therefore, the objective of this study was to examine the effects of four concentrations of VC supplemented for an average of 102 d prior to harvest on cattle performance, carcass characteristics, and blood metabolites of steers receiving a 40% DDGS, high S diet.

Materials and Methods

Yearling Angus-cross steers (n = 140) were transported to the Iowa State University Beef Nutrition Farm (Ames, IA) where steers were weighed, de-wormed, vaccinated with Pyramid 3, and were identified with a unique ear tag. Steers were started on a common receiving diet for 7 d, followed by four, 7-d step-up diets in preparation for the finishing diet (Table 1). Ultrasound measures were conducted by a certified technician on d -19 or -14 prior to start of the study, capturing REA, percent intramuscular fat of the REA, 12th rib back fat thickness (**BF**), and rump fat thickness.

At the initiation of the study, two consecutive day weights were taken and steers were blocked by initial BW (950 ± 56.1 lbs), stratified within blocks by ultrasound-measured initial intramuscular fat (3.6% ± 0.30), and randomly assigned to 1 of 4 treatments (5 steers/pen, 7 pens/treatment), including: 1) no VC control (**CON**), 2) 5 g VC·steer^{-1}·d^{-1} (**5VC**), 3) 10 g VC·steer^{-1}·d^{-1} (**10VC**), and 4) 20 g VC·steer^{-1}·d^{-1} (**20VC**). A VC premix containing Vitashure C50 (a rumen protected ascorbate, 50% VC product; Balchem Corp.) and DDGS was used to introduce VC to the diet. The inclusion rate of the VC premix was adjusted, based on weekly DMI averages for each treatment, in order to maintain the designated VC content of 5, 10, or 20 g VC in the diet. Prior to receiving the assigned study diets, steers were implanted with Component TE-IS. Single day weights were collected every 28 d and consecutive final BW were determined over the 2 d immediately prior to the harvest day. Two d before harvest, in conjunction with collection of final BW, ultrasound measures (REA, percent intramuscular fat of REA, BF, and rump fat thickness) were determined. Jugular blood was collected for plasma analysis of VC, glucose, and insulin, and serum analysis of non-esterified fatty acids (**NEFA**) from 2 steers/pen prior to feeding on d 0 and 2 d prior to harvest.

Steers were harvested by block on 3 separate dates, d 91 (n = 40 steers; 2 heaviest blocks), d 105 (n = 40 steers, middle 2 weight blocks), and d 112 (n = 60 steers, 3 lightest blocks) when greater than 60% of steers in a pen were estimated by visual appraisal to have at least 0.5 inches of back-fat. Steers were harvested at a commercial packing facility in Denison, IA, where carcasses were graded according to USDA standards. Data were collected from harvested animals [(n = 136); data were not collected from four steers due to rail-outs at the packing facility (1 on d 105 and 3 on 112)] and included HCW, marbling score, BF, KPH, REA, quality grade (**QG**) and yield grade (**YG**).

Results

Dry matter intake decreased (P = 0.004; Table 2) as VC concentration increased in the diet, while G:F tended to increase ($P = 0.08$) with increasing VC inclusion to the diet throughout the finishing period. Vitamin C inclusion did not affect ADG ($P = 0.89$) or final BW ($P = 0.48$). No differences due to VC supplementation ($P \geq 0.22$) were observed among final ultrasound data (data not shown). As designed, supplemental VC intake was different ($P < 0.01$) among treatments. Sulfur intakes closely followed DMI and linearly decreased ($P = 0.01$; Table 2) with increasing concentrations of VC in the diet.

Plasma and serum metabolites are presented in Table 3. Final plasma ascorbate concentrations showed a quadratic response to supplemented VC ($P = 0.02$), in which the 5VC cattle exhibited lesser ($P \leq 0.01$) plasma ascorbate compared to the CON and 20VC cattle, but were not different ($P = 0.21$) from the 10VC cattle. The CON cattle tended to have greater plasma VC ($P = 0.08$) and lesser plasma insulin ($P = 0.07$) concentrations compared to the VC supplemented cattle. Increasing VC inclusion did not affect plasma glucose ($P = 0.35$) or serum NEFA ($P = 0.12$).

Hot carcass weight and BF were not affected ($P \geq 0.27$) by increasing inclusion of VC (Table 4). Increasing VC inclusion linearly increased ($P = 0.02$) REA, as the addition of 10 or 20 g of VC to a high S diet increased ($P \leq 0.03$) REA approximately 3.8 to 4.2 cm^2 compared to the CON cattle. The linear increase in REA by VC inclusion subsequently resulted in a linear decrease ($P = 0.02$) in YG, and a linear increase ($P = 0.03$) in proportion of YG1 carcasses due to supplemental VC addition to the high S diet. Marbling score and QG were not affected by dietary treatment ($P \geq 0.32$). A tendency ($P = 0.06$) for a quadratic effect of KPH was noted, in which the 20VC tended to have less KPH compared to the 5VC and 10VC, but was not different from CON cattle.

Discussion

Vitamin C supplementation linearly increased the REA of steers, with the greatest increases observed in the 10VC and 20VC treatments. Similarly, Japanese long-fed steers supplemented with 88 mg VC·lb $BW^{-1}\cdot d^{-1}$ (rumen by-pass VC source) or 50 g VC·$steer^{-1}\cdot d^{-1}$ of L-ascorbic acid-2-phosphate displayed greater REA compared to un-supplemented counterparts. Conversely to the present study results, our previous VC study using calf-fed steers reported no beneficial effect of supplementing 10 g VC·$steer^{-1}\cdot d^{-1}$ during the entire finishing period to steers fed varying concentrations of dietary S (0.22, 0.34, or 0.55%) on REA. However, the mechanisms by which VC may be altering muscle growth and REA are currently unknown.

Vitamin C supplementation did not influence marbling score in the present study; however, other researchers have observed increases in marbling score when VC was supplemented during the finishing period. Specifically, an increase in marbling score of 3.25 to 5.75 (according to the Japanese grading scale), an approximate equivalent to the USDA marbling scores of modest and moderately abundant, was reported when Japanese-long fed cattle were supplemented with 88 mg VC·lb $BW^{-1}\cdot d^{-1}$ (for approximately 600 d finishing period). Also, our previous VC study reported that the inclusion of VC (10 g·$steer^{-1}\cdot d^{-1}$) to calf-fed steers (approximately 8 to 9 mo of age) consuming a 0.55% S diet for 149 d increased marbling scores from $slight^{98}$ ($Select^{+}$) to $small^{70}$ ($Choice^{-}$) when compared to the non-VC supplemented steers consuming the 0.55% S diet. The mechanism by which supplemental VC may impact marbling scores of cattle remains to be elucidated.

Increasing the inclusion rate of VC tended to increase feed efficiency of steers, evident by a decrease in DMI of approximately 0.66 to 1.76 lbs/d with no differences in ADG or final BW among the four treatments. Our previous VC study, reported no influence of VC supplementation on feed efficiency, but cattle were less efficient when dietary S was greater than 0.34%. However, amongst poultry and swine, increases in feed efficiency have been observed with VC supplementation, specifically in stressful situations such as heat stress and weaning.

Currently, the NRC (1996) does not specify a daily VC requirement for cattle because of their ability to synthesize VC from glucose in the liver. Plasma ascorbate concentrations of healthy beef cattle, across all aspects of production, range from 2,400 to 4,700 µg/L, and they are as low as 294 to 742 µg/L in finishing steers consuming a 0.55% S diet. Plasma ascorbate concentrations decrease during the fattening period. In the present study, all cattle were fed a high S diet and no decreases in plasma ascorbate were noted during the finishing period; however, it is unknown how plasma ascorbate concentrations of steers consuming a high S diet may have compared with ascorbate concentrations in steers consuming a low S diet because such a diet was not examined in the present study.

Despite supplementation of a rumen-protected VC source to three of the four treatment groups, the un-supplemented CON cattle exhibited the greatest plasma ascorbate concentration. While the reason for the unexpected plasma ascorbate differences is unknown, it may be related to individual animal variation or may be the result of changes in endogenous production of VC due to VC supplementation. It has been reported that exogenous supplementation of VC to mice decreased the production of VC by the liver, which suggests that the production of endogenous VC might be directly related to the concentration of VC in the portal blood.

Our hypothesis was that the supplementation of VC to cattle diets may provide a sparing mechanism for glucose to be used for other body functions rather than the synthesis of VC. However, glucose and NEFA concentrations were not different between treatments. Alternately, others have reported lesser concentration of circulating glucose in cattle supplemented with 50 g·$steer^{-1}\cdot d^{-1}$ of L-ascorbic acid-2-phosphate for the entire finishing period compared to those supplemented for a portion (early or later) or not receiving supplemental VC at all during the finishing period. Similar to the findings of the present study, these authors also reported no difference in NEFA concentration among treatments. Interestingly, the supplementation of VC in the present study tended to increase plasma insulin concentrations by approximately 0.37 to 0.57μg/L compared to CON steers. No additional information is available concerning the influence of VC on plasma insulin concentrations in feedlot cattle.

In conclusion, the results of this study suggest that the supplementation of 5 to 20 g VC·steer^{-1}·d^{-}, during the later finishing period (91 and 112 d prior to harvest), to yearling steers consuming a high S diet increases REA and may potentially improve feed efficiency, while having limited effects on blood metabolites and only a tendency to affect other carcass characteristics. However, further research is required to determine the exact mechanism by which VC supplementation is altering feed efficiency and supporting muscle development.

Table 1. Ingredient composition of finishing diets (% DM basis).

Ingredient	Common Diet[1]
Corn	45.0
Corn dried distiller's grains[2,3]	40.0
Chopped hay	6.5
Corn silage	5.5
Limestone	1.4
Salt	0.3
Vitamin A premix[4]	0.1
Trace mineral premix[5]	0.035
Rumensin90[6]	0.01
Calcium sulfate[7]	0.60
S[8], %	0.54
Calculated composition[9]	
% Lipid	5.08
Vitamin E, IU·lb^{-1} diet DM	699.46

[1]Treatments: CON: control; 5VC: 5 g vitamin C·steer^{-1}·d^{-1}; 10VC: 10 g vitamin C·steer^{-1}·d^{-1}; 20VC: 20 g vitamin C·steer^{-1}·d^{-1}.
[2]Vitashure C (donated by Balchem Corp., New Hampton, NY) replaced distillers grains plus solubles (DDGS), by 0.11 to 0.43% diet DM, to achieve the target level of vitamin C per steer per day.
[3]Four loads of DDGS (POET; Jewell, IA) were used during the trial, S concentrations were: 0.97, 1.04, 0.96, and 0.96% and fat content: 7.83, 6.91, 5.90, and 6.25%.
[4]Vitamin A premix contained 4,400,000 IU·kg^{-1}.
[5]Provided the following trace minerals (ppm of diet): 30 Zn as $ZnSO_4$; 20 Mn as $MnSO_4$; 0.5 I as $Ca(IO_3)_2(H_2O)$; 0.1 Se as Na_2SeO_3; 10 Cu as $CuSO_4$; and 0.1 Co as $CoCO_3$
[6]Provided at 27g/t diet (donated by Elanco Animal Health).
[7]Calcium sulfate was included at an average of 0.60% diet DM (range of 0.47 to 0.67%), at the expense of DDGS, to targeted S content in the diet.
[8]S content for the four treatments are repeated measures least squares mean averages throughout the entire study.
[9]Lipid content was calculated from the analyzed lipid content of individual ingredients and vitamin E concentrations were calculated based on NRC values for each ingredient.

Table 2. **The effect of varying concentrations of supplemental vitamin C (VC) on dry matter intake, gain, and efficiency of steers consuming a common high S (0.55% S) diet.**

	CON[1]	5VC[1]	10VC[1]	20VC[1]	SEM	Contrast Statements[2] *P* values		
Live performance						CON vs. VC	Linear VC	Quad VC
Initial weight[3], lbs	950	953	950	950	0.9	0.40	0.61	0.27
Final weight[3], lbs	1329	1318	1333	1318	8.0	0.56	0.48	0.55
DMI[4,5], lbs/d	25.1	23.8	24.4	23.3	0.33	0.004	0.004	0.65
ADG[4,6], lbs/d	3.67	3.56	3.76	3.61	0.130	0.84	0.89	0.71
G:F[4,6]	0.150	0.152	0.158	0.160	0.0042	0.16	0.08	0.61
S intakes[7], g/d	59.2	57.7	57.0	54.8	0.79	0.01	0.01	0.82
Carcass-adjusted performance[8]								
Final weight, lbs	1327	1320	1333	1316	7.7	0.62	0.42	0.44
ADG, lbs/d	3.28	3.19	3.34	3.17	0.066	0.63	0.45	0.44
G:F	0.133	0.136	0.139	0.140	0.0033	0.19	0.14	0.61

[1]Treatments: CON: control; 5VC: 5 g vitamin C$\cdot$steer$^{-1}\cdot$d^{-1}; 10VC: 10 g vitamin C$\cdot$steer$^{-1}\cdot$d^{-1}; 20VC: 20 g vitamin C$\cdot$steer$^{-1}\cdot$d^{-1}.

[2]Contrast Statements: CON vs. VC = no vitamin C vs. vitamin C; Linear VC = linear effect of vitamin C; Quad VC = quadratic effect of vitamin C.

[3]A 4% pencil shrunk was applied to weights.

[4]Dry matter intake, S intake, ADG, and G:F were analyzed as repeated measures.

[5]Week $P < 0.001$; Treatment by week $P > 0.41$.

[6]Month $P < 0.001$; Treatment by month $P \geq 0.95$.

[7]Week $P < 0.001$; Treatment by week $P < 0.001$.

[8]Carcass-adjusted performance values are based on final BW calculated from HCW divided by the average dressing percent of 61% for all treatments; a 4% pencil shrink was applied to initial weights prior; ADG and G:F were calculated over the total days on feed.

Table 3. The effect of varying concentrations of supplemental vitamin C (VC) on blood metabolites of steers consuming a common high S (0.55% S) diet.

	CON[1]	5VC[1]	10VC[1]	20VC[1]	SEM	Contrast Statements[2] *P* values		
						CON vs. VC	Linear VC	Quad VC
Plasma metabolites								
Ascorbate[3], µg/L	1,454.0	1,186.2	1,304.2	1,436.4	64.8	0.08	0.53	0.02
Insulin[3], µg/L	1.28	1.65	1.85	1.69	0.19	0.07	0.23	0.11
Glucose[3], mg/dL	99.27	98.43	96.08	103.64	3.31	0.98	0.35	0.23
Serum NEFA[3], µEq/L	189.69	175.18	170.82	228.58	19.6	0.93	0.12	0.11

[1]Treatments: CON: control; 5VC: 5 g vitamin C·steer^{-1}·d^{-1}; 10VC: 10 g vitamin C·steer^{-1}·d^{-1}; 20VC: 20 g vitamin C·steer^{-1}·d^{-1}.

[2]Contrast Statements: CON vs. VC = no vitamin C vs. vitamin C; Linear VC = linear effect of vitamin C; Quad VC = quadratic effect of vitamin C.

[3]Jugular blood was drawn prior to feeding 2 d before harvest.

Table 4. **The effect of varying concentrations of supplemental vitamin C (VC) on carcass characteristics[1] of steers consuming a common high S (0.55% S) diet.**

	CON[2]	5VC[2]	10VC[2]	20VC[2]	SEM	Contrast Statements[3] *P* values		
						CON vs. VC	Linear VC	Quad VC
HCW, lbs	851	843	854	843	5.0	0.44	0.40	0.57
Dressing percent	61.4	61.4	61.5	61.4	0.24	0.91	0.82	0.88
12th rib BF, in	0.52	0.51	0.53	0.48	0.024	0.59	0.27	0.47
KPH, %	2.27	2.37	2.39	2.20	0.07	0.53	0.32	0.06
REA[4], in^2	13.16	13.41	13.75	13.81	0.181	0.03	0.02	0.29
Yield grade	3.28	3.17	3.15	2.93	0.10	0.09	0.02	0.86
Marbling score[5]	478	465	461	456	14.83	0.32	0.34	0.66
Quality grade[6]	3.28	3.0	3.0	3.0	0.16	0.16	0.33	0.35

[1]Cattle were harvested on 3 separate days by blocks: d 91 (n = 40); d 105 (n = 39); d 112 (n = 57)
[2]Treatments: CON: control; 5VC: 5 g vitamin C·$steer^{-1}$·d^{-1}; 10VC: 10 g vitamin C·$steer^{-1}$·d^{-1}; 20VC: 20 g vitamin C·$steer^{-1}$·d^{-1}
[3]Contrast Statements: CON vs. VC = no vitamin C vs. vitamin C; Linear VC = linear effect of vitamin C; Quad VC = quadratic effect of vitamin C
[4]Ribeye area
[5]Marbling scores: slight: 300, small: 400, modest: 500
[6]Quality grade: 2: $Select^+$, 3: $Choice^-$, 4: Choice